Recent Developments in Superconducting Magnet Technology Relevant to eRHIC

Presented by
Brett Parker, BNL-SMD

- **Serpentine Coil Winding Technique**
  - **Custom Compact Designs for IR Magnets**
- **Detector Integrated Dipole (DID)***
  - **Improved Beam Separation Schemes**

**Please note that many of the DID viewgraphs are taken directly from a talk given by Andrei Seryi to the IRLC Theory Club on 19 November 2005 at SLAC.*

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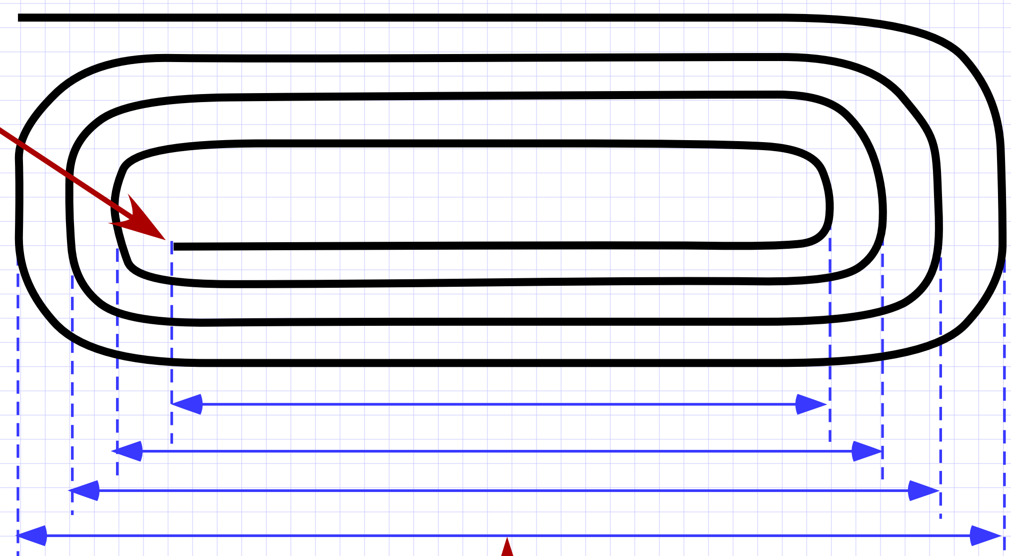
Issues Stemming From Standard Coil Winding Technique (i.e. HERA-II Lessons).

BEPC-II cold mass is much more complicated than HERA-II. So had to look for ways to improve coil structure. Initially we tried simple extension to double-layer coils, but discovered significant issues....

The return lead is trapped inside the coil winding near the pole.

Schematic HERA-II Style Coil Winding

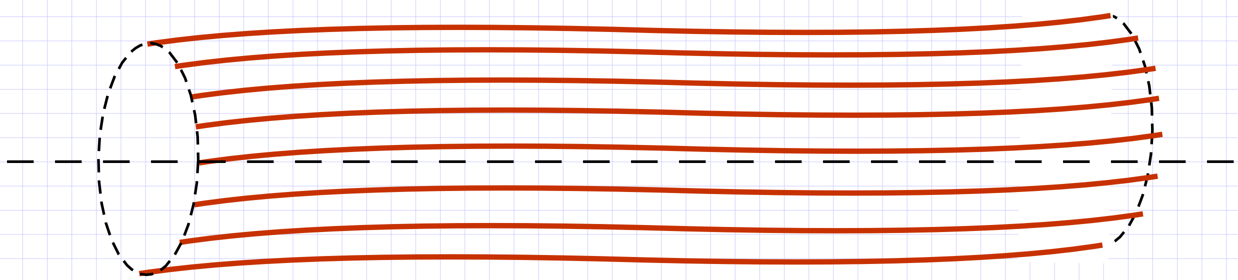


"Planar Pattern"

For a short coil the change of straight section length with turn number makes it very hard to achieve good harmonic quality ("...ends are important").

Deliberately Provocative observation:

Imagine that every turn takes the same shape in its path in space independent of angle.



Then each turn gets the same longitudinal integral weighting with the consequence that the integral harmonics are the same as that given by the 2D cross section!

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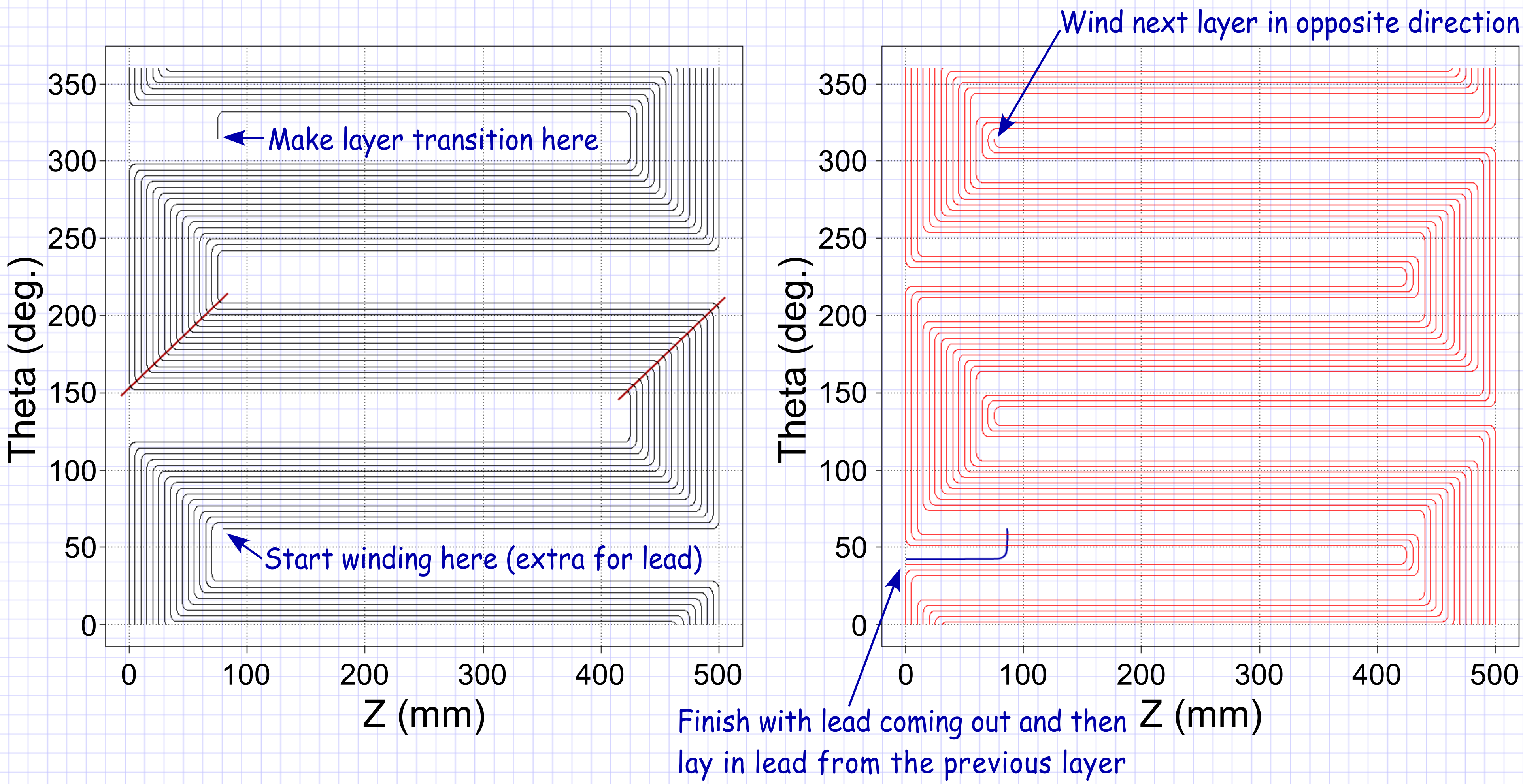
The BNL Serpentine Scheme for Direct Winding Superconducting Magnets.

Unlike a planar pattern, a Serpentine winding keeps going around support tube (360°=0°)



Entire pattern for one layer can be put down at one time and poles are open to ends.

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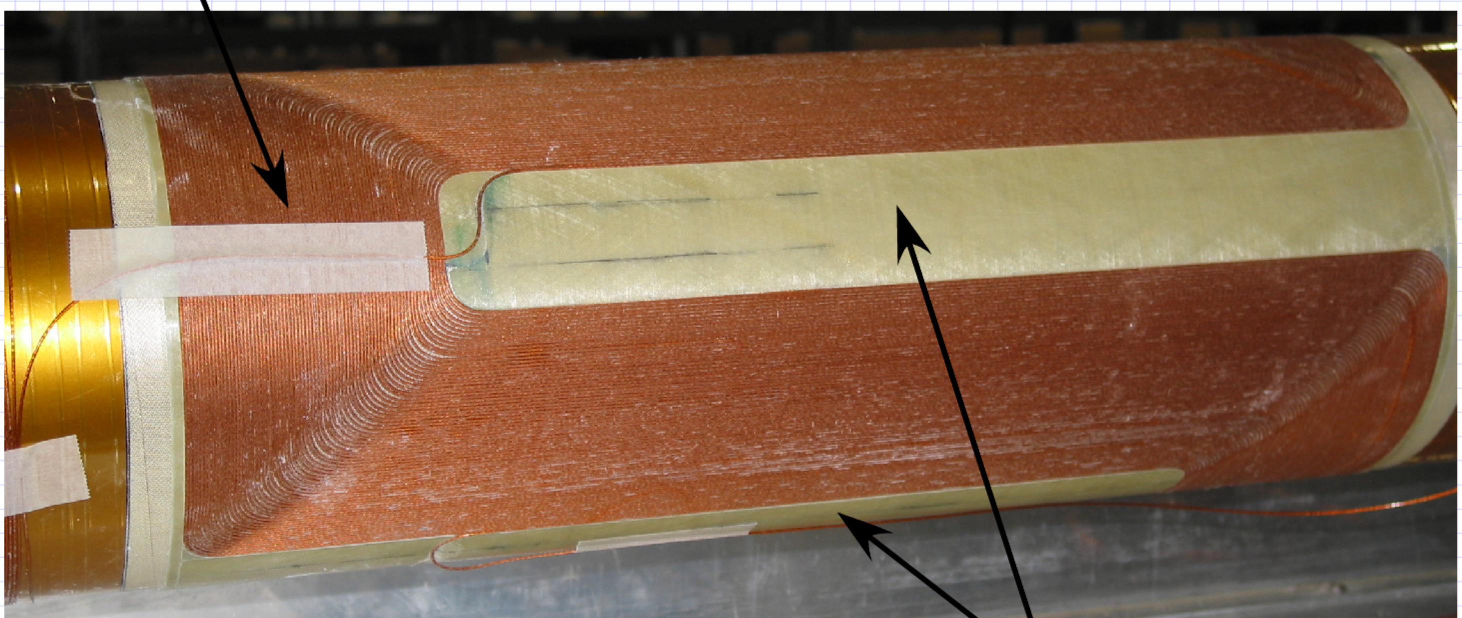
Start BEPC-II Superconducting IR Magnet Production: First SCQ Coil Pattern.

When winding continues the second layer pattern will be open here (allowing the current leads to exit the coil pack).



Example

Simple G10 spacers fill in pole regions.

See http://www.bnl.gov/magnets/BEPCII/Overview.asp & http://www.bnl.gov/magnets/Staff/Parker/serpentine_review.pdf.

First Pattern Wound for JPARC Combined Function & Skew-Dipole Corrector Magnets.

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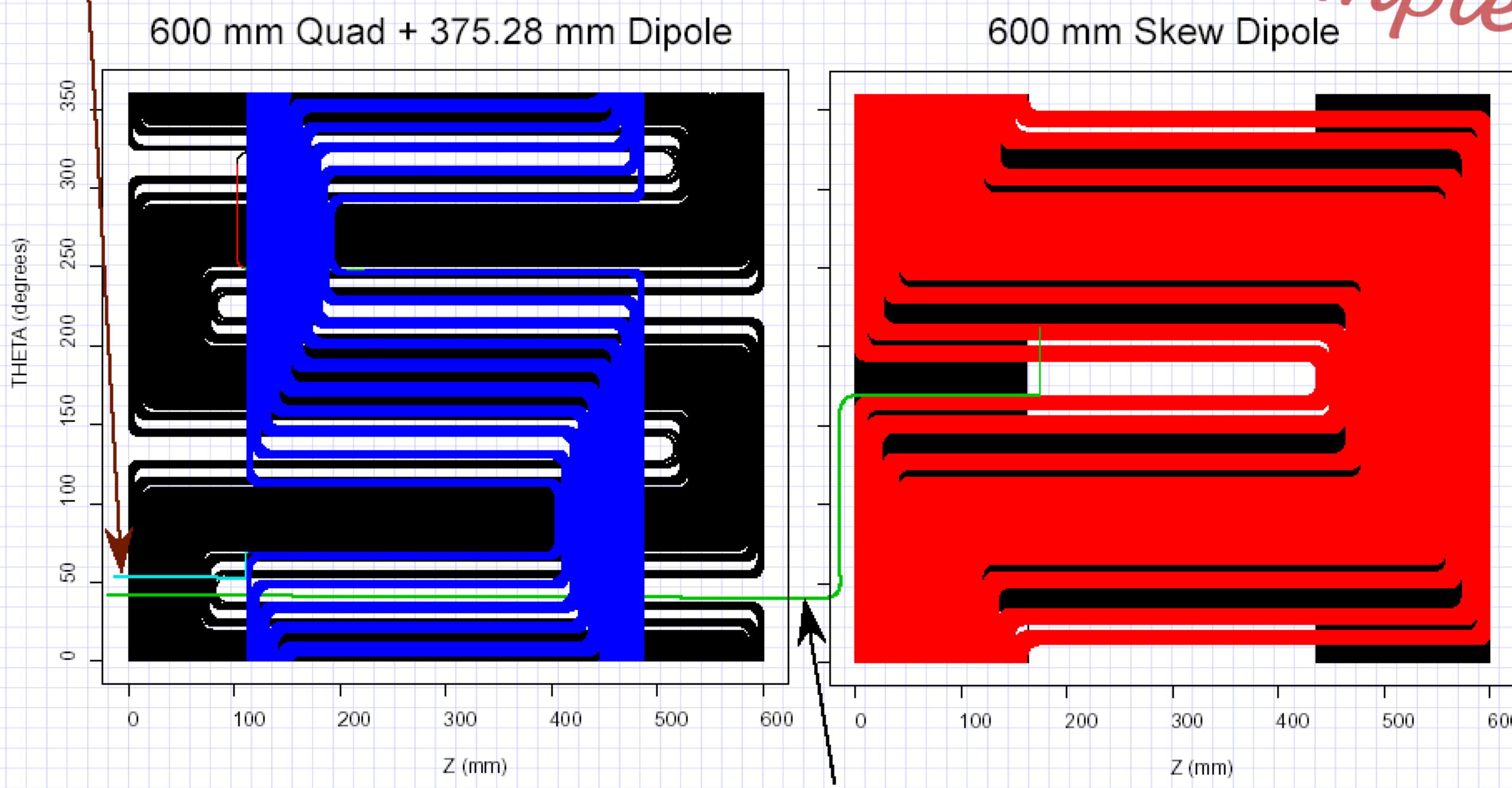
Example

Path of combined function lead pair.



Path of skew dipole lead pair.

Very Tight radial budget!

See http://www.bnl.gov/magnets/Staff/Parker/vc21jan04.pdf for details.

Compact Superconducting Coils for the ILC Final Focus at 20 mr X-ing Angle.

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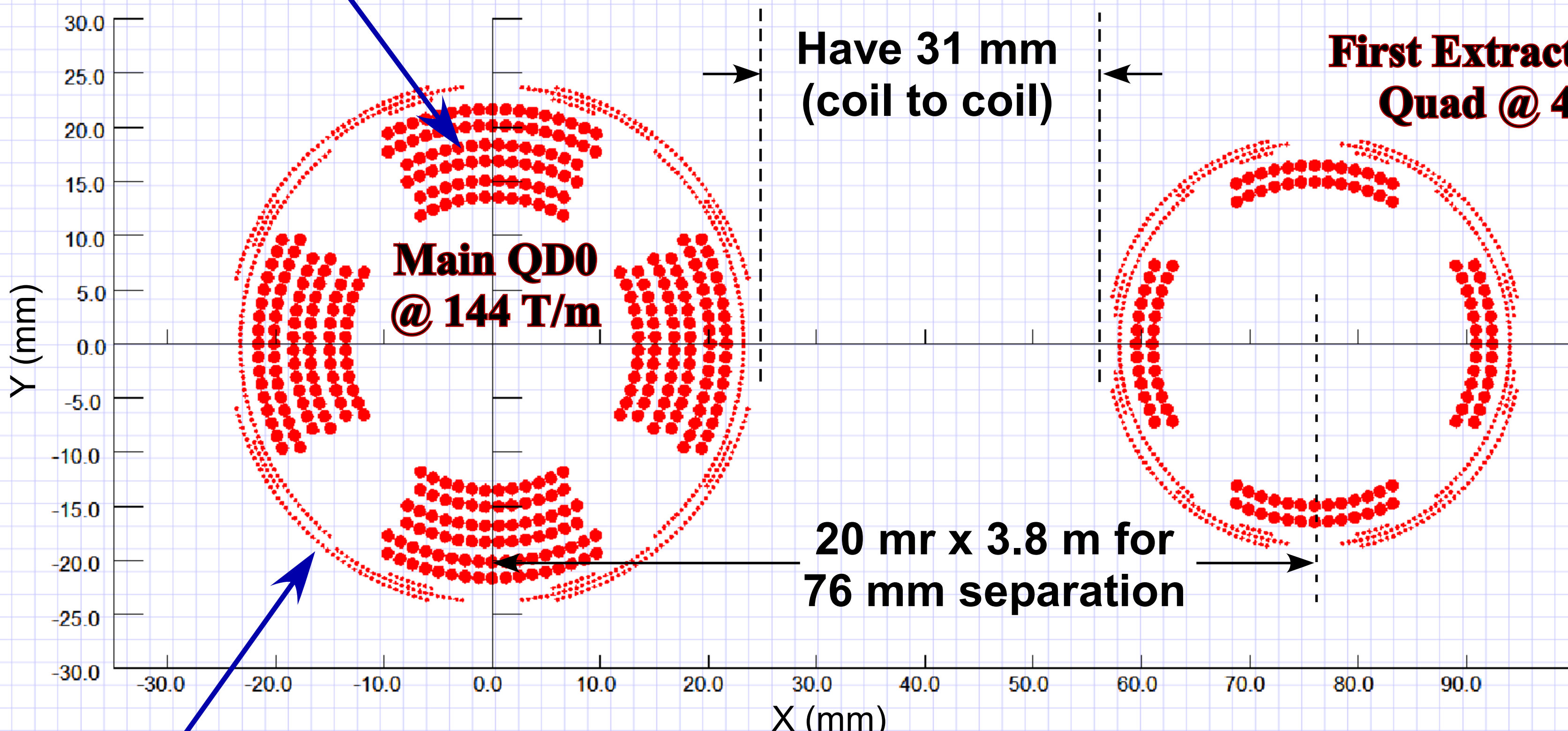
At 1.9°K plan to go from 10 to 6 layers for main coil.

Fringe fields are compensated.



Use trick to get leads out from poles with overlapping dipole, skew dipole and skew quadrupole winding for both magnets.

See http://www-conf.slac.stanford.edu/mdi/talks/CrossingAngle/ParkerCompactSCQ.pdf for more information.

Can we wind 6-around-1 cable with such a small bend radius?

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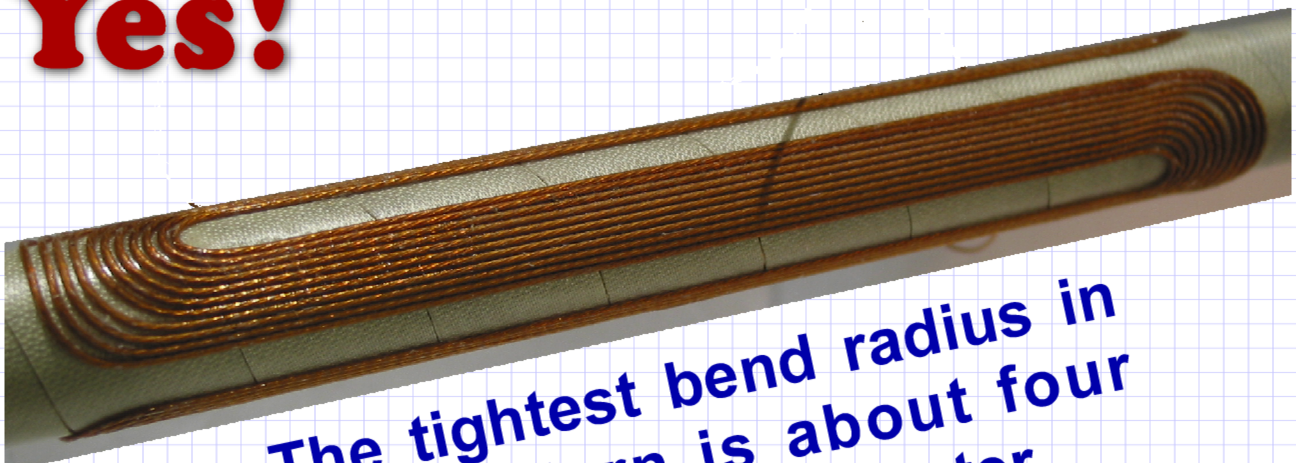
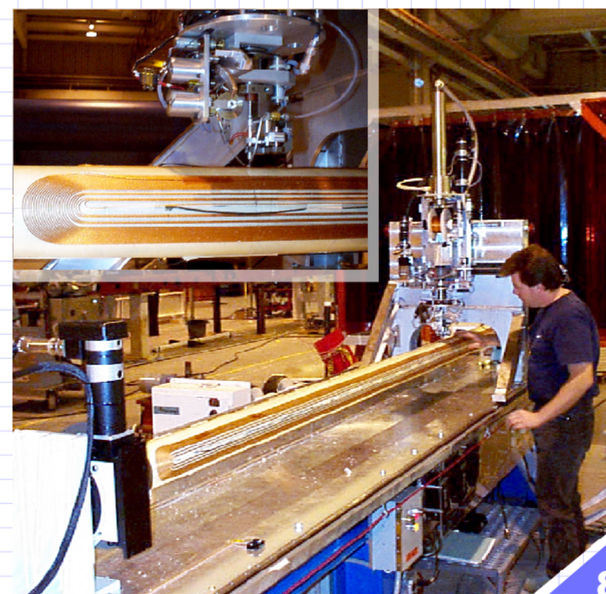
Yes!

Quadrupole pattern with 1 mm cable wound on 25.4 mm diameter tube.



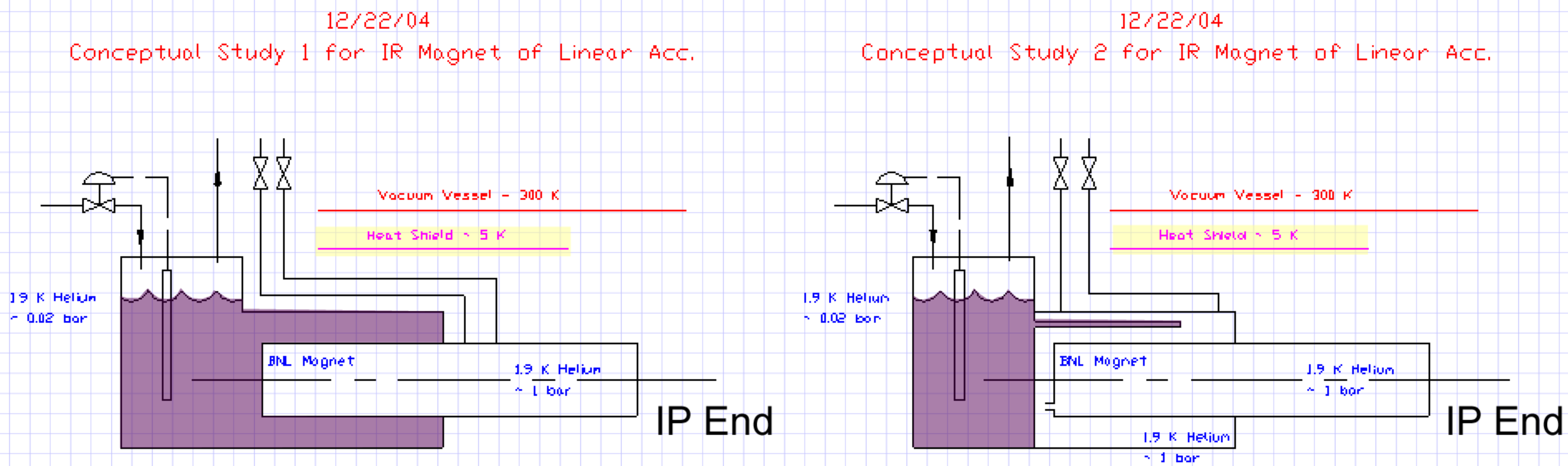
The tightest bend radius in this pattern is about four times the cable diameter.

Idea was to try "semi-automatic" winding with a mechanical assist for the first turn.



By the third corner John Escallier had found process parameters that worked for automatic winding of the rest of the coil (two layers were wound).

Conceptual Study for Cooling an ILC Compact FF Magnet at 1.9°K.*



It is possible keep the IP end small since superfluid helium can conduct heat away even through a small (but non-zero!) annular space. Then further out from IP we arrange to heat exchange between pressurized helium and a reduced pressure helium bath.

Note: 5°K Heat Shield and Control Valves.

- Trade off space for coils for space for supports and heat shield. Hopefully yields overall better design.

*K. C. Wu, BNL/SMD

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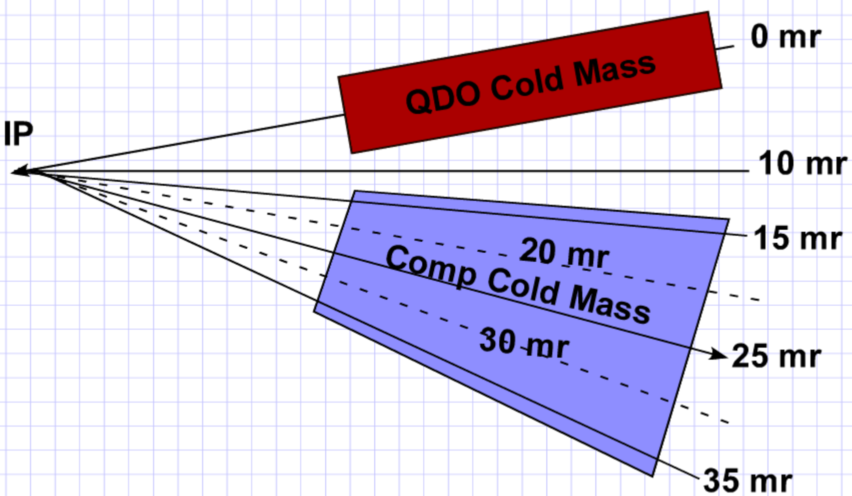
Fringe Field Compensator Design that Uses Tapered Magnet Coil Patterns.

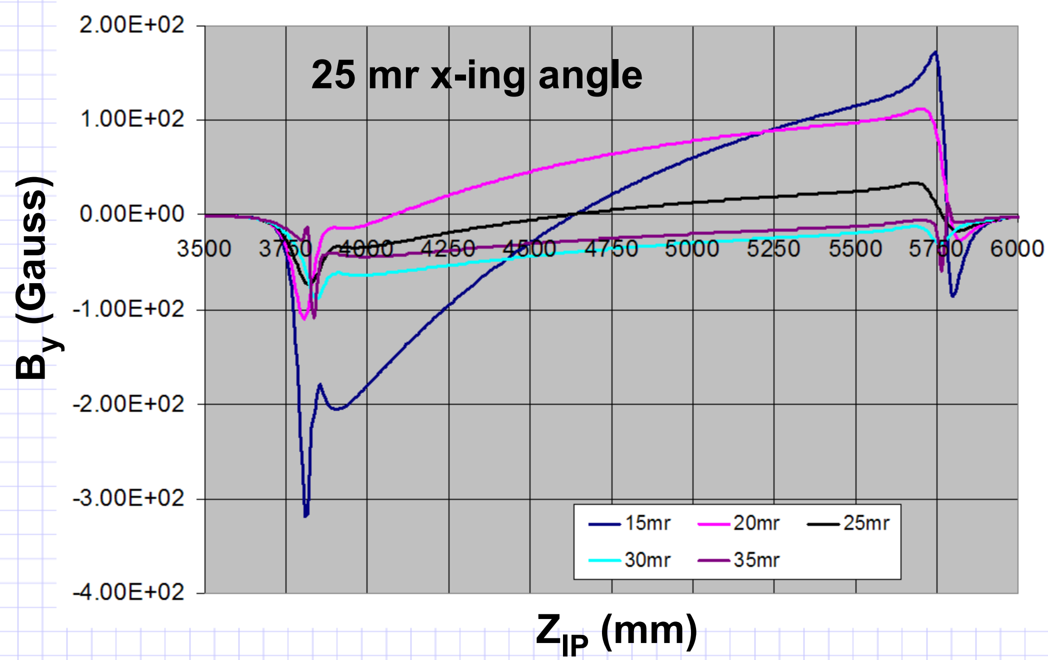
Gamma-Gamma IR Geometry Schematic



Note: X-ing angle is 25 mr and gg opening is ±10 mr so in magnet frame γγ ranges from 15 to 35 mr.

Compensator has dipole, quad & sextupole coils.

Compensated External Field for Various Lines from IP



Designs can use tapered coils.

Here I have taken L^*=3.8 m and G_{QDO}=144 T/m

See http://www-project.slac.stanford.edu/lc/bdir/Meetings/beamdelivery/2005-01-25/index.htm for details.

A New Option to Have an "Invisible" Dipole Inside Experiment, the DID.

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Novel Method of Compensation of the Effects of Detector Solenoid on the Vertical Beam Orbit in a Linear Collider

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(Dated: January 18, 2005)

This paper presents a method for compensating the vertical orbit change through the Interaction Region (IR) that arises when the beam enters the Linear Collider detector solenoid at a crossing angle. Such compensation is required because any deviation of the vertical orbit causes degradation of the beam size due to synchrotron radiation, and also because the nonzero total vertical angle causes rotation of the polarization vector of the bunch. Compensation may be necessary to preserve the luminosity or to guarantee knowledge of the polarization at the Interaction Point (IP). The most effective compensation is done locally with a special dipole coil arrangement incorporated into the detector (Detector Integrated Dipole). The compensation is effective for both e^+e^- and e^-e^- beams, and the technique is compatible with beam size compensation either by the standard method, using skew quadrupoles, or by a more effective method using weak antisolenoids.

PACS numbers: 29.17.+w , 41.85.-p , 41.75.Ht , 29.27.-a , 29.27.Hj , 84.71.Ba

Submitted to PR Special Topics: Accelerators & Beams

I. INTRODUCTION

The future electron-positron International Linear Collider (ILC) requires high luminosity which can only be achieved by colliding very small nanometer scale beams. In the earlier LC projects, NLC/GLC and TESLA, the

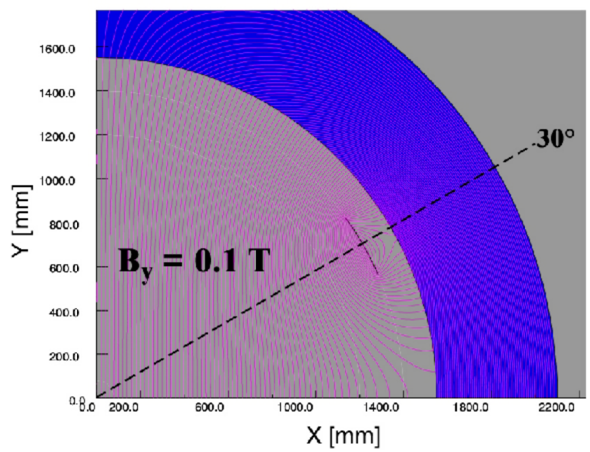
verses the magnetic field of the detector at an angle and thus will be deflected in the vertical plane. The change in the vertical orbit causes degradation of the beam size due to synchrotron radiation (SR), and also causes rotation of the polarization vector if the total vertical angle is nonzero.

First Public Presentation of a Crude DID Concept at EIC 2002 Workshop.

A cylindrical yoke is compatible with a low field strength dipole plus regular solenoid.

Interaction Region Subgroup

Dipole (¼ Model + Boundary Conditions)



- Dipole with 0.1 T does not require excessive superconductor (even with R_{coil} = 1.4 m).
- Wind on top detector solenoid coil.
  - Avoid radiation length at small R.
  - Avoid issues with coil torques.
  - Even the partial coil shown at left, gives good field quality for beams.

Design shown has 10^{-5} field uniformity at R = 80 mm.

An early, very crude, horizontally bending version of a DID was first suggested at the 2002 EIC Workshop. This was later taken up by Andrei Seryi and myself with vertical bending to do "local orbit compensation" for the detector solenoid kicks that come from having a crossing angle at the ILC.

See URL: http://www.bnl.gov/magnets/Staff/Parker/TalkEIC2002/FullTalkEIC.pdf

Issues Arising From Colliding Beams With a Crossing Angle in a Solenoid.

In the solenoid without quads and with crossing angle:

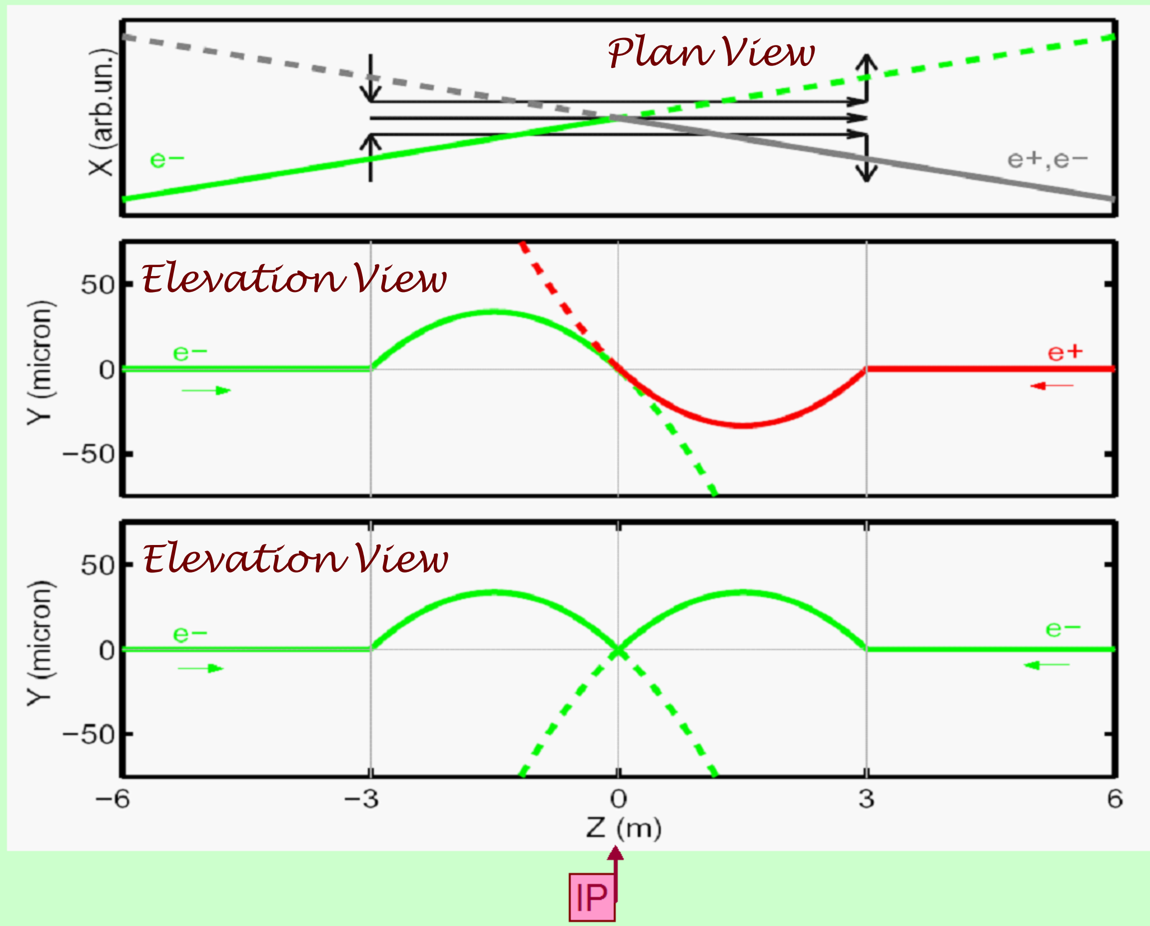
e+e- collide head-on

e-e- collide at an angle

Deviation of vertical orbit causes SR beam size growth

IP angle is not nice for polarization diagnostics

IP angle is also not good for e-e- luminosity



Orbits for e+e- and e-e- cases for 20 mrad total crossing angle, 3m half solenoid length, 5T max field of the detector, 250GeV/beam

"Optimization of Linear Collider Interaction Region: Weak Antisolenoids & Detector Integrated Dipole," A. Seryi, Theory Club Talk, SLAC, November, 2004.

Using DID for Local Orbit Compensation Inside the Experimental Detector.

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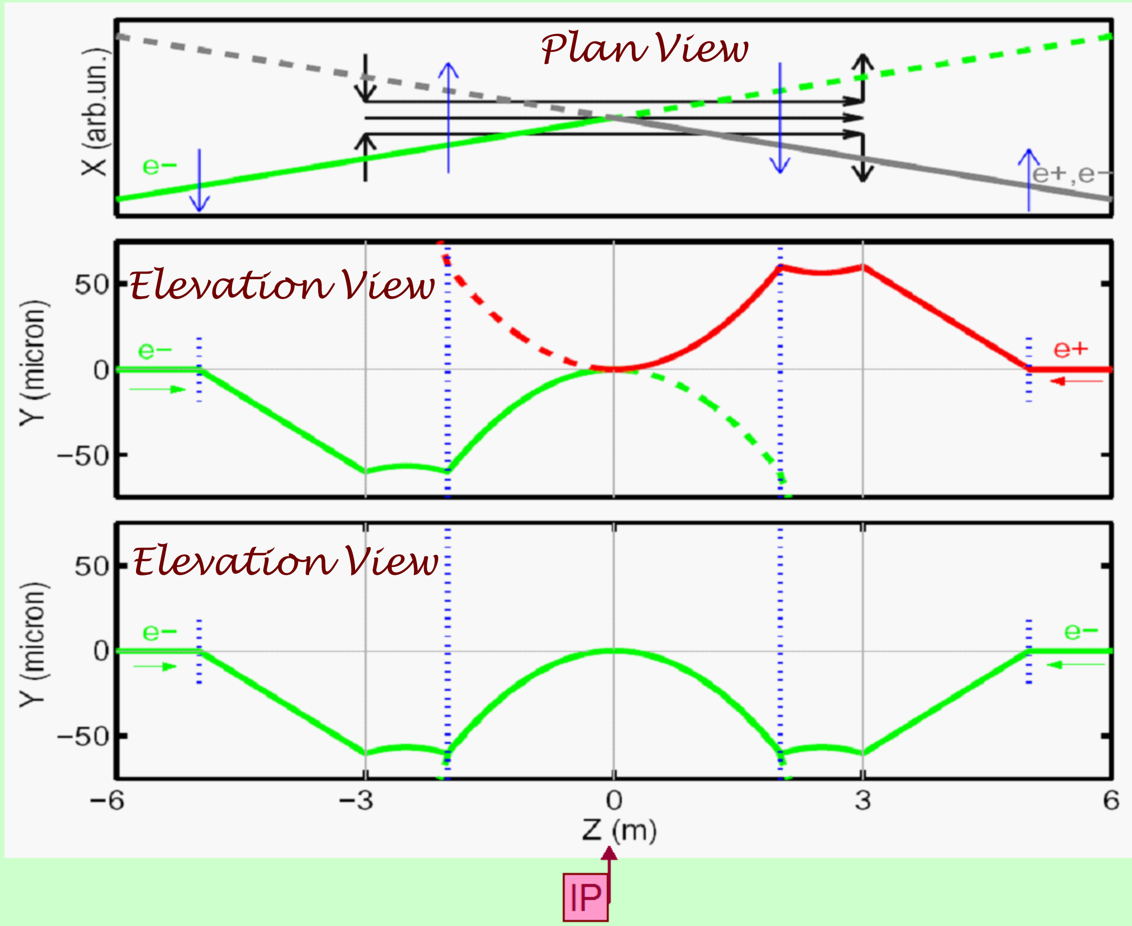
Compensation of the vertical angle can be done using two kicks per side

Same compensation field works for e+e- and e-e-

To minimize orbit deviation, compensation must be done locally, i.e. a kick must be inside of detector

Flattening the orbit to minimize SR can be done in a similar way



Orbits for e+e- and e-e- cases for 20 mrad total crossing angle,
3m half solenoid length, 5T max field of the detector, 250GeV/beam
The IP angle is compensated by two kicks per side

“Optimization of Linear Collider Interaction Region: Weak Antisolenoids & Detector Integrated Dipole,” A. Seryi, Theory Club Talk, SLAC, November, 2004.

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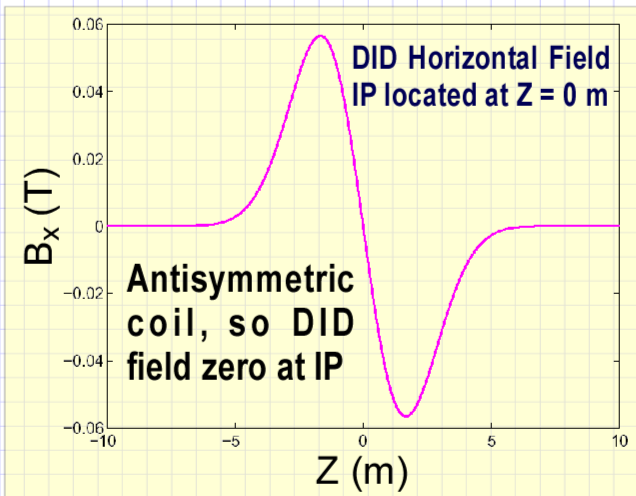
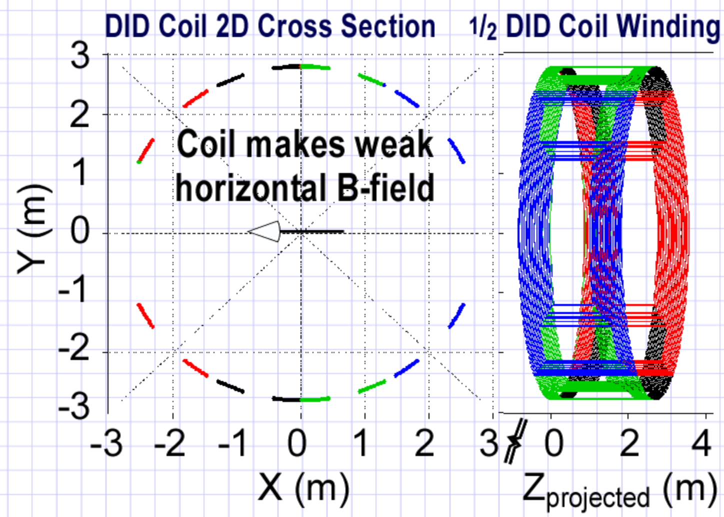
Limited Synrad Effects by "Pointing" Solenoid Field Lines to Incoming Beams.

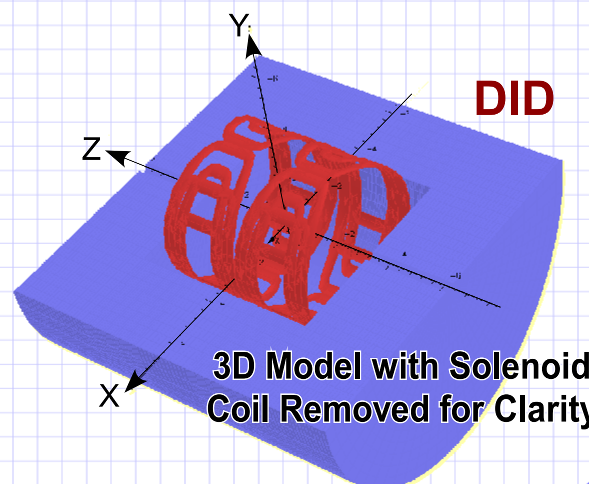
Recent Invention: Detector Integrated Dipole (DID).

For a weak enough field, not much penalty (magnetic stored energy) in filling detector with dipole field. So integrate dipole coil within detector solenoid cold mass.

Local correction inside detector done without adding extra material near the IP.







In effect can align incoming beams with solenoidal field to reduce synrad and preserve polarization, whether colliding e−e+ or e−e−, and independent of the incident energy.

First Thoughts on Using a DID for a Luminosity Upgrade of PEP-II at SLAC.

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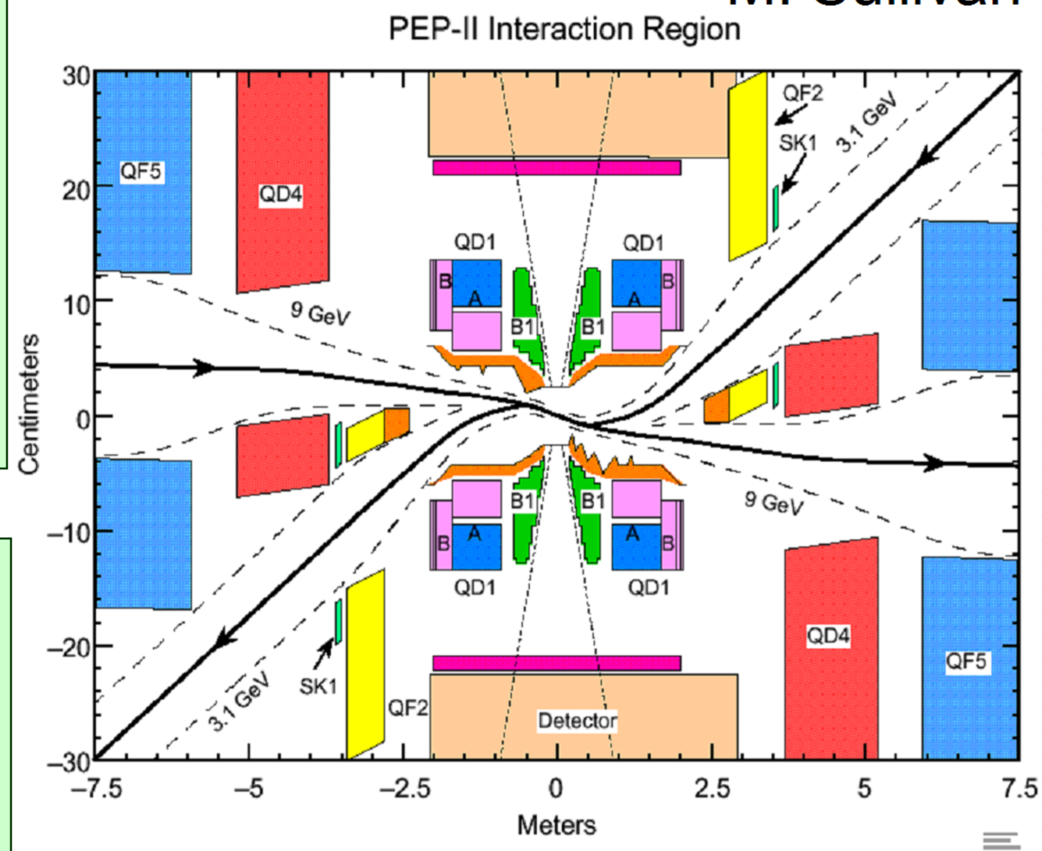
Upgrade scenarios considered, for example, replacing part of B1 with quadrupole field, in order to decrease L* and allow smaller vertical beta-function at the IP. Introduction of the small crossing angle is also considered, in order to provide sufficient separation at the parasitic crossings

M. Sullivan



Brett Parker has suggested to consider using DID for PEP-II IR upgrade. In this case, one can remove the B1 altogether, allowing reduction of L*. Crossing angle may not be necessary

On the next pages several very preliminary and not-optimized configurations will be shown

In the PEP-II design report, bunch separation at parasitic crossings is ~12 sigma, and LER SR losses (for 2.1A beam) are 3kW/side from QD1 and 6kW/side from B1, i.e. total 18kW, or 8.6 kW / Ampere

“Optimization of Linear Collider Interaction Region: Weak Antisolenoids & Detector Integrated Dipole,” A. Seryi, Theory Club Talk, SLAC, November, 2004.

What Style DID Should We Use, i.e. Symmetric or Anti-Symmetric?

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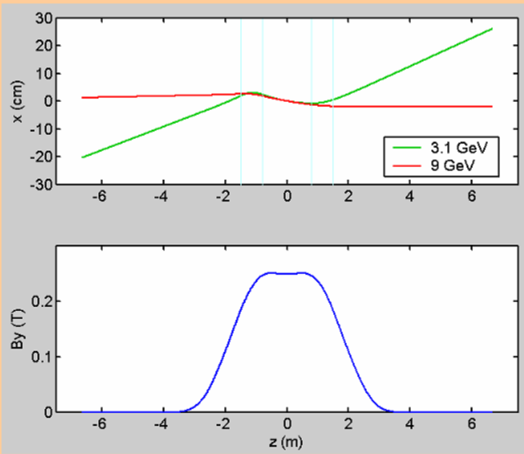
Symmetrical DID



QD1 offsets: right = -3 cm, left = 14 cm

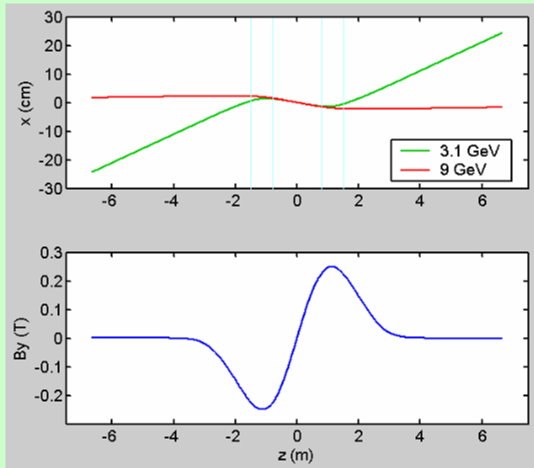
separation at 0.63m is 3.12 mm, 13.1 sigma *
-0.63m is 3.06 mm, 12.8 sigma
separation at 1.26m is 14.8 mm, 31.1 sigma
-1.26m is 14.6 mm, 30.7 sigma
separation at 1.89m is 41.2 mm, 57.6 sigma
-1.89m is 40.8 mm, 57.2 sigma
separation at 2.52m is 71.5 mm, 75.0 sigma
-2.52m is 71.5 mm, 75.0 sigma

LER losses 20.7 kW/A

Large separation at parasitic crossings, but also large SR losses

(* assumed emittance X=40nm, betaX=28cm)
light blue lines show location of QD1

Anti-Symmetrical DID



QD1 offsets: right = -4 cm, left = 4 cm

separation at 0.63m is 0.95 mm, 4.01 sigma
-0.63m is 0.93 mm, 3.90 sigma
separation at 1.26m is 9.17 mm, 19.2 sigma
-1.26m is 9.00 mm, 18.9 sigma
separation at 1.89m is 32.5 mm, 45.5 sigma
-1.89m is 32.2 mm, 45.1 sigma
separation at 2.52m is 60.7 mm, 63.7 sigma
-2.52m is 60.7 mm, 63.7 sigma

LER losses 8.0 kW/A

Small SR losses, but too small separation at parasitic crossings

Example

Procedure: Use a DID plus right & left quadrupole offsets in order to maintain the present PEP-II IR geometry.

"Optimization of Linear Collider Interaction Region: Weak Antisolenoids & Detector Integrated Dipole," A. Seryi, Theory Club Talk, SLAC, November, 2004.

What Style DID Should We Use, i.e. Symmetric or Anti-Symmetric?

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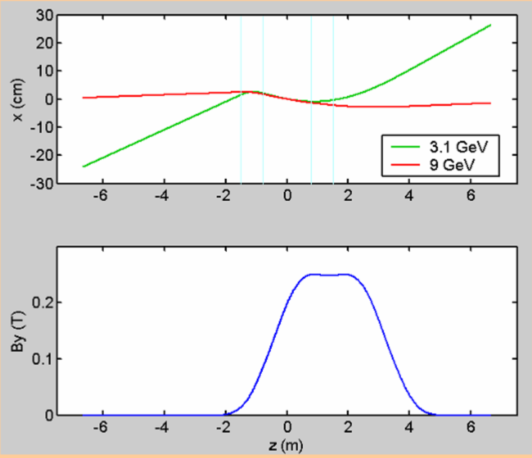
Symmetrical DID, shifted



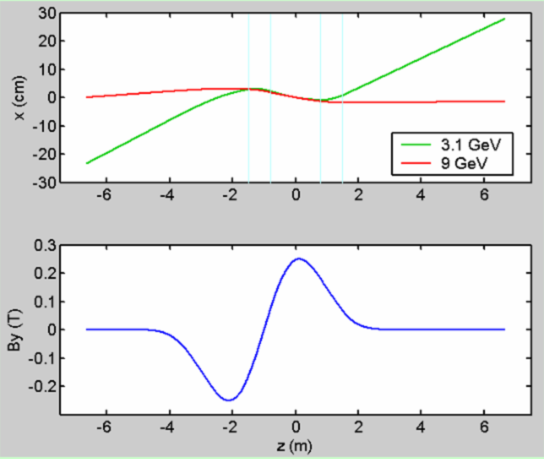
QD1 offsets: right = -1 cm, left = 11 cm

separation at 0.63m is 2.77 mm, 11.6 sigma
-0.63m is 2.71 mm, 11.4 sigma
separation at 1.26m is 12.0 mm, 25.2 sigma
-1.26m is 11.8 mm, 24.9 sigma
separation at 1.89m is 29.9 mm, 41.8 sigma
-1.89m is 29.7 mm, 41.5 sigma
separation at 2.52m is 54.2 mm, 56.9 sigma
-2.52m is 54.2 mm, 56.9 sigma

LER losses 14.7 kW/A

Large separation at parasitic crossings, reduced SR losses

Anti-Symmetrical DID, shifted



QD1 offsets: right = -5 cm, left = 8 cm

separation at 0.63m is 3.07 mm, 12.9 sigma
-0.63m is 3.00 mm, 12.6 sigma
separation at 1.26m is 15.4 mm, 32.4 sigma
-1.26m is 15.2 mm, 31.9 sigma
separation at 1.89m is 45.6 mm, 63.9 sigma
-1.89m is 45.3 mm, 63.4 sigma
separation at 2.52m is 78.1 mm, 82.0 sigma
-2.52m is 78.1 mm, 82.0 sigma

LER losses 12.2 kW/A

Large separation at parasitic crossings, reasonably small SR losses

Example

Procedure: Use a DID plus right & left quadrupole offsets but don't center the DID.

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Some Very Preliminary Observations Regarding DID and a PEP-II Upgrade.

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These preliminary configurations show that it may be in principle possible to upgrade PEP-II IR using Detector Integrated Dipole

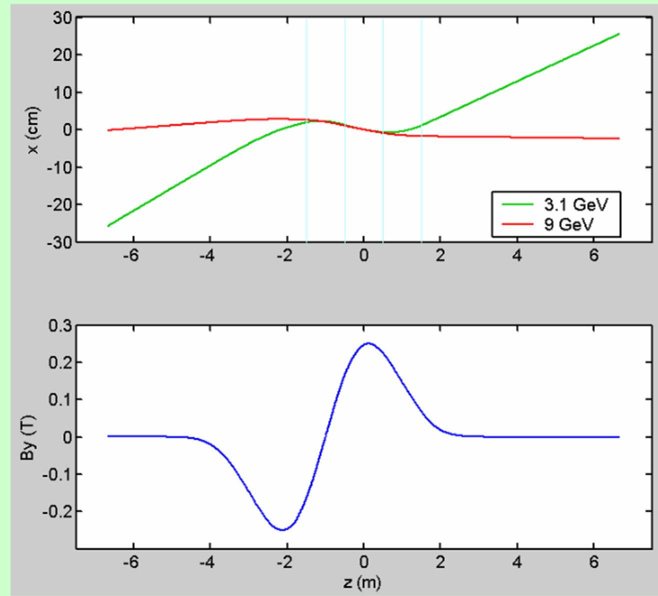
It would allow to remove the B1, and reduce L* and the betaY*

Sufficient separation at the parasitic crossings may be achieved even without the crossing angle

There are many degrees of freedom to further optimize the field and trajectories

Feasibility of modification of the BaBar solenoid, to include DID, is the main question

Shorter L*, anti-Symmetrical shifted DID



QD1 offsets: right = -3.8 cm, left = 6.7 cm

separation at 0.63m is 3.28 mm, 13.8 sigma
-0.63m is 3.20 mm, 13.4 sigma
separation at 1.26m is 18.3 mm, 38.5 sigma
-1.26m is 18.1 mm, 38.0 sigma
separation at 1.89m is 47.1 mm, 66.0 sigma
-1.89m is 46.8 mm, 65.5 sigma
separation at 2.52m is 77.6 mm, 81.5 sigma
-2.52m is 77.6 mm, 81.5 sigma

LER losses 8.9 kW/A

Large separation at parasitic crossings, reasonably small SR losses

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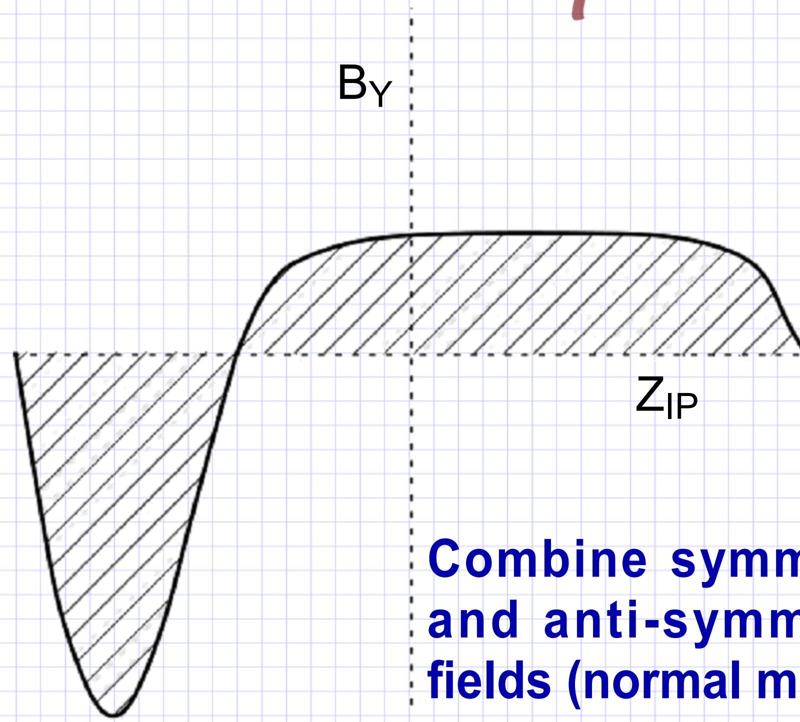
Using a Combination of Symmetric & Asymmetric DIDs Instead of Shifting?

Further optimization may include, for example, asymmetric configuration of the field as shown here

The total field integral is zero, and shorter part has higher field

This field would result from powering the coils in combination of symmetric and anti-symmetric mode, when the edges are limited by location of the detector yoke

Another Option



Combine symmetric and anti-symmetric fields (normal modes).

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